# Investigation of meteorological drought characteristics of the Great Man-Made River Region: a case study of drought in Libya

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# Abstract

Drought is a hidden natural hazard that involves complex climatic systems and has significant environmental and social consequences. Due to the current state of catastrophic climatic occurrences, there has been an increase of interest in monitoring of droughts in recent years. In this study, meteorological drought analysis for five monitoring stations in the Great Man-Made River region located in Libya was conducted. The Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) methods were used to determine meteorological droughts utilizing monthly total precipitation data, mean monthly temperatures data, and total monthly precipitation. The drought analysis of the Great Man-Made River region using DrinC software for 1-, 3-, 6-, and 12-months SPI values were researched. According to the SPI-12-month index values, the driest period was determined by 86% in the Tripoli Airport and Nalut station, and the least dry period was determined in the Sirt station by 39%. It was found that the year 2000–2001 was one of the driest years in all stations, and the other years with high drought rates were 1981–1982, 1984–1985, and 1992–1993.


# 1. Introduction

Drought is one of the current natural disasters significantly affecting different regions on small and large scales. Drought creates environmental, economic, and social issues in the affected regions. Among the various disasters known in the world, drought is termed a natural disaster. Although, different definitions have been made of the drought (McMahon and Arenas, 1982). During drought, a lack of moisture normally causes a serious hydrological imbalance. Due to this condition, drinking water is usually used for precipitation, which has serious implications for humans and the earth. Due to water deficiency, the affected areas also suffer dry weather and long-lasting water scarcity. According to Hagman et al. (1984), drought is more common than any other disaster globally. Droughts are the most complex of all-natural disasters that have affected humans, but drought's least understood nature has been described (Beran and Rodier, 1985). In a specific period and under specific circumstances, the area's decrease in water availability is termed drought. Drought has been affecting various regions of the world every year (Hisdal and Tallaksen, 2003).

With the emergence of drought as a result of the lack of rainfall, the water, and water resources, which were the source of life, decreased in the region, and accordingly, it might harm agricultural productivity. In this condition, some issues might arise under the phenomena of the agricultural and hydrological drought, which occurred because of Libya's meteorological drought at a time when Libya suffered a dry period. These are certain agricultural sectors, which is one of Libya's most essential sectors, that had suffered a downfall due to the agricultural drought. Similarly, the products cultivated by the farmers, considered to be the most basic elements of this sector, are generally dependent on the climate. Therefore, a decrease in rainfall usually causes problems such as a decrease in the yield of the products and the inability to meet the country's food needs (Öztürk et al., 2002).

Considering the severity, duration, and effects of the drought, there are certain drought types, including meteorological-, agricultural-, hydrological-, and socioeconomic droughts (Wilhite and Glantz, 1985). Meteorological drought is expressed depending on the degree and duration of drought. Depending on the rainfall data, it is the first type of drought that we come across. Since its effect depends on the rainfall, the rainfall period constitutes a normal level in that drought type. It is evaluated in seasonal, water-year, or annual time scales (Şen, 2009). Agricultural drought is examined as a result of a shortage of rainfall due to meteorological drought and deterioration of soil water. The water demand of a plant depends on that plant's biological properties along with the growth or stages of the physical and biological properties of the soil (Wilhite, 2000). Hydrological droughts mean a lack of water in the hydrological system. It was a type of drought that manifested itself at unusually low levels in rivers, lakes, reservoirs, and groundwater (Van Loon, 2015). The socioeconomic drought had occurred as a result of linking the supply and demand of some economic goods or services with meteorological, hydrological, and agricultural drought factors. Therefore, drought usually happens due to an increase in demand for supply goods and a decrease in climate factors (Van Loon, 2015).

Drought is a hidden natural hazard that involves complex climatic systems and has significant environmental and social consequences. Due to the current state of catastrophic climatic occurrences, there has been an increase in interest in drought consequences and monitoring in recent years. Drought events have an impact on many of the GEOSS (Global Earth Observation System of Systems) Societal Benefit Areas (SBAs). Drought has created a link between various fields, including agriculture sustainability, food security, ecosystem functions and services, biodiversity, carbon stocks, water resources, and wildfires, to name a few. According to the IPCC's 5th Assessment Report, a drop in precipitation, coupled with increasing temperatures associated with drought occurrences, is expected, particularly in the Mediterranean Basin, resulting in lower water availability for natural and agricultural systems and human requirements. Hence this study aims to determine the longest drought period in the study area. The main concern is to find one of the driest years of all the stations and to find the years with high drought rates. For the purpose of this study, located in the Great Man-Made River region, meteorological drought analysis will be conducted for five monitoring stations in Northern Libya. For the drought analysis using DrinC software of the Great Man-Made River region for 1-, 3-, 6-, and 12-months, Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) values are conducted and discussed.

# 2. Background

Drought is a natural disaster with multiple varieties. According to the purpose of the study and the data used, many methods assessed drought and its occurrence in various factors. According to methods developed by Palmer (Palmer, 1965), to translate drought into the language of mathematics, Palmer Drought Severity Index (PDSI) based on precipitation and temperature data (McKee et al., 1993), had been utilized solely based on the precipitation data with the Standardized Precipitation Index (SPI) to explore the meteorological drought (Nalbantis, 2008). An attempt is made by Aksoy (2018) for the drought analysis with the SPI method using the data of 35 stations in the Gediz Basin with at least ten years of measurement between 1960 and 2016. Their study utilized SPI values for the periods of 3-, 6-, and 12-months. For all periods in the basin, they found that 32% of the time had a mild drought, 8.8% moderate drought, 5% severe drought, and 2.3% of severe intensive drought (Aksoy, 2018). Al-Qinna et al. (2011) used SPI and Normalized Difference Vegetation Index (NVDI) to explore the average day to day temperature and metrological drought analysis of the Hashemite Kingdom of Jordan between 1970–2005. According to their results based on the drought indices, extreme drought was observed in the period 1999–2000, and it was stated that the country was exposed to drought cycles for the upcoming 35 years. Moreover, Apak (2009) analyzed the drought origins in stations with long-term rainfall measurements in the Aegean Region, by using the SPI method for two periods, 1938–1970 and 1971–2006. Their research mentioned the effectiveness of the investigation in two periods in determining the severity of the drought and observed that in the second period, both the number of dry years and the drought intensity increased compared to the first period. Arslan et al. (2016) investigated the droughts that occurred in the Gediz Basin by using the SPI index for 1-,3-,6-,9-,12-, and 60-month periods using monthly precipitation data of 8 meteorological precipitation stations between 1973 and 2013. Their study showed that the droughts experienced in recent years lasted longer. For periods of 12- and 60-months, it has been stated that the drought period has increased by 3–7 times in recent years compared to the past.

## 3. Methods

# 3.1. Study area and data description

This study aimed to determine drought sensitivity and calculate dry years to illustrate the driest years in the Great Man-Made River region using the SPI and RDI based on the DrinC software in five meteorological stations using data from 1980 to 2009. Consequently, temporal changes in drought index values were examined through drought analysis. Northern Libya is the study area as rainfall is decreasing near the Libyan coast. The study area is located between the longitudes of 9 and 25 easts and 30 and 33 latitudes of the north. It should be noted that the analysis is made through monitoring data from the stations based on the atmospheric droughts using the precipitations index of droughts, as seen in Table 1 and Fig. 1.

Table 1
Rainfall monitoring stations and their geographic locations.

| Station Number | Station Name | Coordinate and Altitudes |
|---|---|---|
| 62007 | Zuara | 32,53 N12,05 E 03 m |
| 62010 | Tripoli Airport | 32,40 N13,09 E 81 m |
| 62002 | Nalut | 31,52 N10,59 E 621 m |
| 62016 | Misurata | 32,19 N15,03 E 32 m |
| 62019 | Sirt | 31,12 N16,35 E 13 m |

### 3.1.1. Al Serir Basin

This basin is extended from the Serir region to the Mediterranean coast. Its waters were latent at a layer of 600 meters deep and contained 1000 km³ of water. Therefore, 84% of this water was of good quality and ready for usage (Murray, 1952).

### 3.1.2. Murzuq Basin

The second main basin is situated in the Fezzan region southwest of Libya, covering an area of 450,000 Units and containing 4800 km³ of water. It is famous for its high-quality water and salinity of not more than 300 (ppm) (Abolgma, 1995).

### 3.1.3. Al Hamada Basin

This basin is in the northern Fezzan region and extends along the Jabel Al-Sawda up to the Mediterranean Sea. Studies confirmed that waters of the Serir and Hamada basins are of lower quality (Public Authority for Agricultural Production, 1989).

### 3.1.4. Al Kufra Basin

This basin is located southeast of Jamahiriya. It was the largest of the main underground basins, covering an area of 350,000 km² and containing 3,400 km³ of. Therefore, 90% of this underground reserve capacity was still awaiting exploitation (Public Authority for Agricultural Production, 1989).

## 3.2 The DrinC software

The Drought Indices Calculator (DrinC) was created with the intention of offering a user-friendly tool for calculating a variety of drought indices. The widest potential applicability for various types of droughts (meteorological, hydrological, agricultural) and varied places was a key goal in its design. Drought studies are also seen to be particularly important in dry and semi-arid regions, where data is typically scarce. As a result, the following are the primary criteria for choosing this software:

1. it has relatively low data requirements, allowing the application of the software in many regions.

2. Their results can be clearly interpreted for direct and efficient operational use.

The process is based on these criteria, two recently developed and two more widely known indices are included in DrinC:

- The Reconnaissance Drought Index (RDI)
- The Stream Flow Drought Index (SDI)
- Standardized Precipitation Index (SPI)
- Precipitation Deciles (PD).

They could be easily understood; RDI, SPI and PD referred to the meteorological drought and used as the main determinant the precipitation (and additionally the potential evapotranspiration for RDI only). Further, RDI could also be used for the agricultural drought analysis, as it could adequately describe the water balance, and it is particularly useful when reference periods related to development stages of the crop were selected (Palmer 1965). On the other hand, SDI applied to hydrological drought and had used stream flow as the key determinant (Tsakiris et al., 2010).

Apart from the originally proposed methods of calculation for each index, DrinC incorporated alternative methods that allowed the comparison of the results among the indices. Further, this has given a 3 key advantage to the user, since it had provided the flexibility to select among various options for adjusting the outputs to his particular needs. Following, there is a short presentation and the key characteristics of the drought indices calculated by DrinC (Tsakiris et al., 2010).

## 4. Results And Discussions

In this research, the SPI and RDI values for 1-, 3-, 6- and 12-months are calculated and evaluated. The data used are the values of the monthly total precipitation and monthly mean temperature belonging to five meteorological stations situated in the region of The Great Man-Made River, Libya.

# 4.1. The Zuara Station Meteorological Drought Analysis

The monthly dryness ranged between 48% and 79% according to SPI values. The highest dry period was in August, and the lowest dry period was in October/September, and the dry and humid periods were equal in November and December. The period of drought and moisture for each of 3-, 6-, and 12- months for the SPI values are shown in Fig. 2. The Driest periods with the highest SPI − 3 values are SPI3-3 in April of 54% and the lowest dry period is SPI3-4 July with 46%. Dryness and moisture are equal in SPI6-1 October at 50%, SPI6-2 in April the droughts are 46% and 54% respectively. SPI-12 calculated according to 12-month values dryness is 54% and moisture is 46%.

According to the values of one-month SPI obtained from the monthly rainfall data, the presence of Middly Dry period was determined in July for a period of 15 years. While the Extremely Dry period experienced in November and December 2000–2001, the Extremely Wet period was July 1985–1986. Figure 3 shows the distributions time of SPI values for 3-, 6- and 12-months examination of SPI values. While SPI-3 for October 1981–1982 shows a Severely Dry period, the year 1984–1985 experienced an Extremely Wet period. SPI-3 January for the year 1980–1981 showed a Extremely Dry period. Moreover, the year 1989–1990 was Very Wet. When the SPI values were checked for six months, SPI-6 October 2000–2001 and SPI-6 April 1998–1999 were found to be Severely Dry. According to SPI-12 values, the year 2000–2001 was defined as Extremely Dry, while the year 1984–1985 was Extremely Wet.

# 4.2. The Tripoli Station Meteorological Drought Analysis

The monthly dryness ranged between 46% and 86% according to SPI values. The highest dry period is 86% in July and 76% in June, with the lowest dry 46% period in December and November. Figures 4 demonstrate the 3-, 6- and 12-months dryness and humidity rates in the Tripoli Station. The most dry periods with the highest SPI – 3 values are SPI3-3 in April of 61% and the lowest dry period is SPI3-4 July with 46%. For the periods SPI6-1 in October and SPI6-2 in April, the droughts were 54% and 55%, respectively. SPI-12 calculated according to 12-month values dryness is 46% and moisture is 54%.

The presence of Middly Dry period was determined in month July for a period of 24 years. While the Extremely Dry period was seen in November 2000–2001, the Extremely Wet period was August 2004–2005 (similar July). Figure 5 illustrates the time distributions of SPI values for 3-, 6- and 12-months. The SPI-3 October year 2000–2001 experienced an Severely Dry period, while the year 1980–1981 was Extremely Wet period. The SPI-3 January year 2008–2009 was Severely Dry, while the year 1981–1982 was Extremely wet. The SPI-3 April year 1998–1999 observed an Severely Dry period, while the year 1993–1994 was Extremely Wet period. The SPI-3 July years 1981–1982 and 2006–2007 were Severely Dry, while the year 1996–1997 were identified as Extremely Wet. When the SPI values were checked for six months, SPI-6 October year 2000–2001 was Severely Dry. Moreover, SPI-6 April 1998–1999 was determined to be Severely Dry as well. According to SPI-12 values, the year 2000–2001 was defined as Severely Dry, while the year 1980–1981 was Extremely Wet.

## 4.3. The Nalut Station Meteorological Drought Analysis

Monthly dryness ranged between 45% and 86%. Of the Nalut Station. While the highest dry period was 86% in August, the wet periods was 55% in March, and the lowest wet period was 7% in July. Figure 6 shows 3-, 6- and 12-months dryness and humidity rates. The driest periods with the highest SPI-3 values were SPI3-2 in January (55%), and the lowest dry period was SPI3-1 in October (48%). For the periods SPI6-1 in October and SPI6-2 in April, the droughts and moisture were 52%, and 55%, respectively SPI-12 showed dryness and moisture values at 52%, and 48%, respectively.

According to SPI values obtained from the monthly total rainfall data, while the highest dry period was in December 2000–2001, the highest wet period was July 1988–1989. Figure 7 demonstrates the time distributions of SPI values for 3-, 6- and 12-months. The SPI-3 January year 2004–2005 was Extremely Dry, while the year 1995–1996 was Extremely wet. The SPI-3 April year 1998–1999 observed an Severely Dry period, while the year 1990–1991 was Extremely Wet period. Also SPI-3 July year 2007–2008 was identified as Extremely Wet. When the SPI values are checked for 6 months, SPI-6 October year 1992–1993 and SPI-6 April 1983–1984 were determined to be Severely Dry. According to SPI-12 values, the year 1992–1993 was defined as Severely Dry and the year 1995–1996 Extremely Wet period.

## 4.4. The Misurata Station Meteorological Drought Analysis

The monthly dryness ranged between 39% and 79%. The highest dry period was 79% in August and 71% in June, with the lowest dry period in April (39%). The wet periods were the period with a high moist of 61% in April, and the lowest wet period were 7% in July and 21% August. The periods of drought and moisture for each of 3-, 6-, and 12- months are shown in Fig. 8 The driest periods with the highest SPI-3 values were SPI3-2 in January (54%), and the lowest dry period was SPI3-1 in October (46%). For the periods SPI6-1 in October and SPI6-2 in April, the droughts were 46% and 52%, respectively. SPI-12 showed dryness of 52% and moisture of 48%.

According to monthly SPI values, the presence of Middle Dry was determined in month July and August for long years. While the highest dry/Extremely Dry period was in March 1999–2000, the highest/Extremely Wet period was July 1995–1996. Figure 9 shows the time distributions of SPI values for 3-, 6-, and 12- months. The SPI values for three months show SPI-3 October 1989–1990 and 1992–1993 as Severely Dry period, while 1986–1987 was Very Wet period. While the Severely Dry period was seen year 1984–1985, the year Extremely Wet period was seen at 1994–1995 year due to SPI-3 January. Also the Severely Dry periods were seen at years 1998–1999 and 1980–1981 due to SPI-3 April and SPI-3 July, respectively. When the SPI values were checked for six months, SPI-6 in October year 1993–1994 was arid. Moreover, SPI-6 April 1982–1983 was found to be Severely Dry period as well. According to SPI-12 values, the year 2000–2001 was defined as Severely Dry, while the year 1980–1981 was Extremely Wet.

# 4.5 The Sirt Station Meteorological Drought Analysis

The monthly dryness ranged between 32% and 76% according to SPI values. Monthly dryness ranged between 32% and 76%. The driest period was 76% in June and 59% in September, with the lowest in February (32%). The wet periods were the period with a high moist of 68% in February, and the lowest wet period were 3% in July and 7% in August. Figure 10 illustrates the rates of 3-, 6- and 12-months dryness and humidity in the Sirt Station. The driest periods with the highest SPI-3 values were in July (59%), and the lowest dry period was in January (43%). SPI-12 showed dryness of 55% and moisture of 45%.

According to one-month SPI values, the presence of near-normal was determined in July and August for a period of 28 years, while the highest drier periods were in January 2008–2009, in November 1980–1981 and 2000–2001, and the highest moist period was July 2005–2006. Figure 11 illustrates the time distributions of SPI values for 3-, 6-, and 12-months. The SPI values for three months show SPI-3 October 2000–2001 as an Extremely Dry period, while 1991–1992 was Extremely Wet period. The SPI-3 January year 2008–2009 experienced an Extremely Dry period, while the years 1980–1981 and 1992–1993 was Severely Wet period. The SPI-3 April years 1983–1984 and 1999–2000 were Severely Dry, while the year 1990–1991 was Extremely Wet period. The SPI-3 July year 1980–1981 observed a Moderately Dry period, while the year 1985–1986 was identified as Extremely Wet period. When the SPI values were checked for six months, SPI-6 October year 2000–2001 was found to be Extremely Dry. Additionally, SPI-6 April 1980–1981 was found to be Severely Dry. According to SPI-12 values, the year 2000–2001 was defined as Extremely Dry, while the year 1980–1981 was Extremely Wet period.

The abstract of SPI and RDI results of all station are given in Table 2 and Table 3, respectively. In the monthly RDI analysis for all stations using monthly precipitation data and mean monthly temperatures, it was found that the maximum value of the Reconnaissance drought at Tripoli Airport Station in year 2000–2001 is in November month (-2.98), and in the analysis of RDI-3 it is found that the highest value of drought is in Nalut Station in RDI3-1 October in year 1981–1982 Extremely Dry, in the analysis of RDI-6, it is found that the highest value of drought is in Sirte Station in RDI6-1 October in the year 2000–2001 Extremely Dry, in the analysis of RDI-12, the maximum value of Reconnaissance drought is in Zuara Station in 2000–2001 year Extremely Dry.

Table 2
The abstract of SPI results of all stations

| | | | | | | |
|---|---|---|---|---|---|---|
| **Monthly** | | **Zuara** | **Tripoli Airport** | **Nalut** | **Misurata** | **Sirt** |
| | **Range of Dry %** | **48% – 79%** | **46% – 86%** | **45% – 86%** | **39% – 79%** | **32% -76%** |
| | **The highest Dry period** | **79% August, 71% Jun** | **86% July, 76% Jun** | **86% August, 69% Jun** | **79% August, 71% Jun** | **76% Jun, 59% Sep** |
| | **The lowest Dry period** | **48% Oct – Sep** | **46% Nov-Dec Feb-Mar** | **45% Mar** | **39% Apr** | **32% Feb** |
| | **The highest wet period** | **52% Oct – Sep** | **54% Nov-Dec** | **55% Mar** | **61% Apr** | **68% Feb, 59% Oct** |
| | **The lowest wet period** | **3% July** | **10% August** | **7% July** | **7% July** | **3% July** |
| 3 Monthly | The highest Dry period | 54% SPI3-3 Apr | 61% SPI3-3 Apr | 55% SPI 3 – 2 Jan | 54% SPI 3 – 2 Jan | 59% SPI3-4 July |
| | The lowest Dry period | 46% SPI3-4 July | 46% SPI3-4 July | 48% SPI 3 – 1 Oct | 46% SPI 3 – 1 Oct | 43% SPI3-2 Jan |
| 6 Monthly | Dryness | 50% SPI6-1 Oct | 46% SPI6-1 Oct | 52% SPI6-1 Oct | 46% SPI6-1 Oct | 52% SPI6-1 Oct |
| | Dry | 46% SPI 6 – 2 Apr | 45% SPI 6 – 2 Apr | 55% SPI 6 – 2 Apr | 52% SPI 6 – 2 Apr | 52% SPI6-2 Apr |
| 12 Month | Dryness | 54% | 46% | 52% | 52% | 55% |
| | | **Zuara** | **Tripoli Airport** | **Nalut** | **Misurata** | **Sirt** |
| Monthly | The highest Dry | Dec. (2000–2001) | July (2005–2006) | Dec. (2000–2001) | March (1999–2000) | Feb (1984–1985) |
| | The highest Moist | July (1985–1986) | August (2004–2005) | July (1988–1989) | July (1995–1996) | July (2005–2006) |
| 3 Monthly | The highest Dry | SPI3-3 Apr. (1988–1989) | SPI3-2 Jan. (2008–2009) | SPI3-1 Oct. (1982–1983) | SPI3-3 Apr. (1998–1999) | SPI3-2 Jan. (2008–2009) |
| | The highest Moist | SPI3-1 Oct. (1984–1985) | SPI3-4 July (1996–1997) | SPI3-1 Oct. (1995–1996) | SPI3-2 Jan. (1994–1995) | SPI3-4 July (1985–1986) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 Monthly | The highest Dry | SPI6-1 Oct (.2000–2001) | SPI6-2 Apr. (1998–1999) | SPI6-2 Apr. (1983–1984) | SPI6-1 Oct. (1993–1994) | SPI6-1 Oct. (2000–2001) |
| | The highest Moist | SPI6-1 Oct. (1984–1985) | SPI6-1 Oct. (1980–1981) | SPI6-1 Oct. (1995–1996) | SPI6-1 Oct. (1980–1981) | SPI6-2 Apr. (1985–1986) |
| 12 Month | The highest Dry | SPI – 12 (2000–2001) | SPI-12 (2000–2001) | SPI-12 (1992–1993) | SPI-12 (2000–2001) | SPI-12 (2000–2001) |
| | The highest Moist | SPI-12 (1984–1985) | SPI-12 (2000–2001) | SPI-12 (1995–1996) | SPI-12 (1980–1981) | SPI-12 (1980–1981) |

Table 3
The abstract of RDI results of all stations

| | | **Zuara** | **Tripoli Airport** | **Nalut** | **Misurata** | **Sirt** |
|---|---|---|---|---|---|---|
| Monthly | The highest Dry | November (2000–2001) | November (2000–2001) | December (2000–2001) | March (1999–2000) | Feb (1984–1985) |
| | The highest Moist | August (2005–2006) | August (2004–2005) | July (1988–1989) | July (1995–1996) | July (2005–2006) |
| 3 Monthly | The highest Dry | RDI3-3 Apr (1998–1999) | RDI3-2 Jan (2008–2009) | RDI3-1 Oct (1981–1982) | RDI3-3 Apr (1998–1999) | RDI3-2 Jan (2008–2009) |
| | The highest Moist | RDI3-1 Oct (1984–1985) | RDI3-4 Jul (1996–1997) | RDI3-1 Oct (1995–1996) | RDI3-2 Jan (1994–1995) | RDI3-4 Jul (1985–1986) |
| 6 Monthly | The highest Dry | RDI6-2 Apr (1998–1999) | RDI6-2 Apr (1998–1999) | RDI6-2 Apr (1983–1984) | RDI6-1 Oct (1993–1994) | RDI6-1 Oct (2000–2001) |
| | The highest Moist | RDI6-1 Oct (1984–1985) | RDI6-1 Oct (1980–1981) | RDI6-1 Oct (1995–1996) | RDI6-1 Oct (1980–1981) | RDI6-2 Apr (1985–1986) |
| 12 Month | The highest Dry | RDI-12 (2000–2001) | RDI-12 (2000–2001) | RDI-12 1992–1993) | RDI-12 (2000–2001) | RDI-12 (2000–2001) |
| | The highest Moist | RDI-12 (1984–1985 | RDI-12 (1980–1981 | RDI-12 (1995–1996 | RDI-12 (1980–1981 | RDI-12 (1980–1981 |

# 5. Conclusion And Recommendation

Drought is a natural phenomenon with a variety of consequences. Economic, environmental, and societal effects are all significantly affected by the severe drought. With the current drought occurrence rate due to the lack of rainfall, the region's water, and water resources, which were the source of life, declined, and it's probable that agricultural productivity will suffer significantly. In this situation, various issues could arise as a result of the agricultural and hydrological droughts that occur as a consequence of Libya's meteorological drought. As such, in this paper, meteorological drought analysis was conducted for five monitoring stations in Northern Libya located in the Great Man-Made River region. The SPI and RDI methods were used to determine meteorological droughts using monthly total precipitation data and mean monthly temperatures. Based on the results, the driest time was defined by 86% in the Tripoli Airport and Nalut stations, and the least dry period was found to be in the Sirt station (39%), according to SPI-12-month index data.

In the SPI analysis of all stations monthly, in the Zuara station, it was found that August is driest with a value of 79%. In Tripoli Airport station, it was recorded that July was the driest at a value of 86%. In the Nalut station, it was discovered that August was the driest with a value of 86%, while in the Misurata station, August turned out to be the driest at a value of 79%. In Sirte station, it was revealed that June was the driest month with a value of 76%. This study showed that during the 29-year period, rains decreased in winter and autumn in coastal stations. Considering that rain waters are used for storage in soil and agricultural irrigation in dry seasons, the decrease in winter rainfall may cause issues in terms of agricultural productivity in the long term. Therefore, some measures should be taken to eliminate or reduce the negative impacts of climate change in Libya, as seen by the low rainfall and increased temperatures. The most important of these measures is establishing and implementing new and urgent national plans for water resources management.

It has been determined that the drought index value has decreased in almost all of the periods and stations, that is, the drought has increased. The change process of an important event such as hydrological drought, which causes more economic impact than other types of drought, should be followed over time and necessary technical and social measures should be taken accordingly. Considering that important irrigation works have been carried out using the water resources of basin together with the increasing drought in recent years, it will be beneficial to understand why the water resources in the basin should be used efficiently. For example, wild irrigation should be abondoned and sprinkler irrigation methods should be preferred. In order to take precautions for the future, engineering structures such as underground dams should be built. Plant cultivation, which needs less water, should be given importance.

To monitor hydrological drought in the region, which is subject to transboundary waters, flow observation station data must be measured on a yearly basis in order to identify the trend of hydrological drought and observation stations in this context. Also to improve the effectiveness and performance of Libyan meteorological stations, work must be done to expand the number of synoptic stations, as well as improvements to data completeness, station standards, and operating protocols, as well as frequent training for operational station meteorologists.

It is recommended to study the time period from 2009 to 2021 in order to know and measure indicators related to precipitation, temperature, and drought in the areas studied, as well as areas and stations located in cities where the man-made river does not pass through, in order to know the rainfall rate, temperatures, drought rates, and SPI coefficient, as well as potential shortcomings and restrictions (SPEI) related to groundwater. Also it is recommended that you investigate the stations in Libya's eastern areas, which include Benghazi, Al-Marj, Al-Bayda, Derna, and Tobruk. To study and comprehend rainfall and drought, as well as compute and compare the SPI factor to western locations such as Zuwara, Tripoli, and Misurata. For the cities of Sirte, Ajdabiya, and Benghazi, researchers should perform a study to ascertain the characteristics of drought in successive years for a specific future time period.

A study should be done to identify the number of drought years over a period of more than 25–30 years, compare them to temperatures at various stations, and monitor the growth in evaporation and transpiration.

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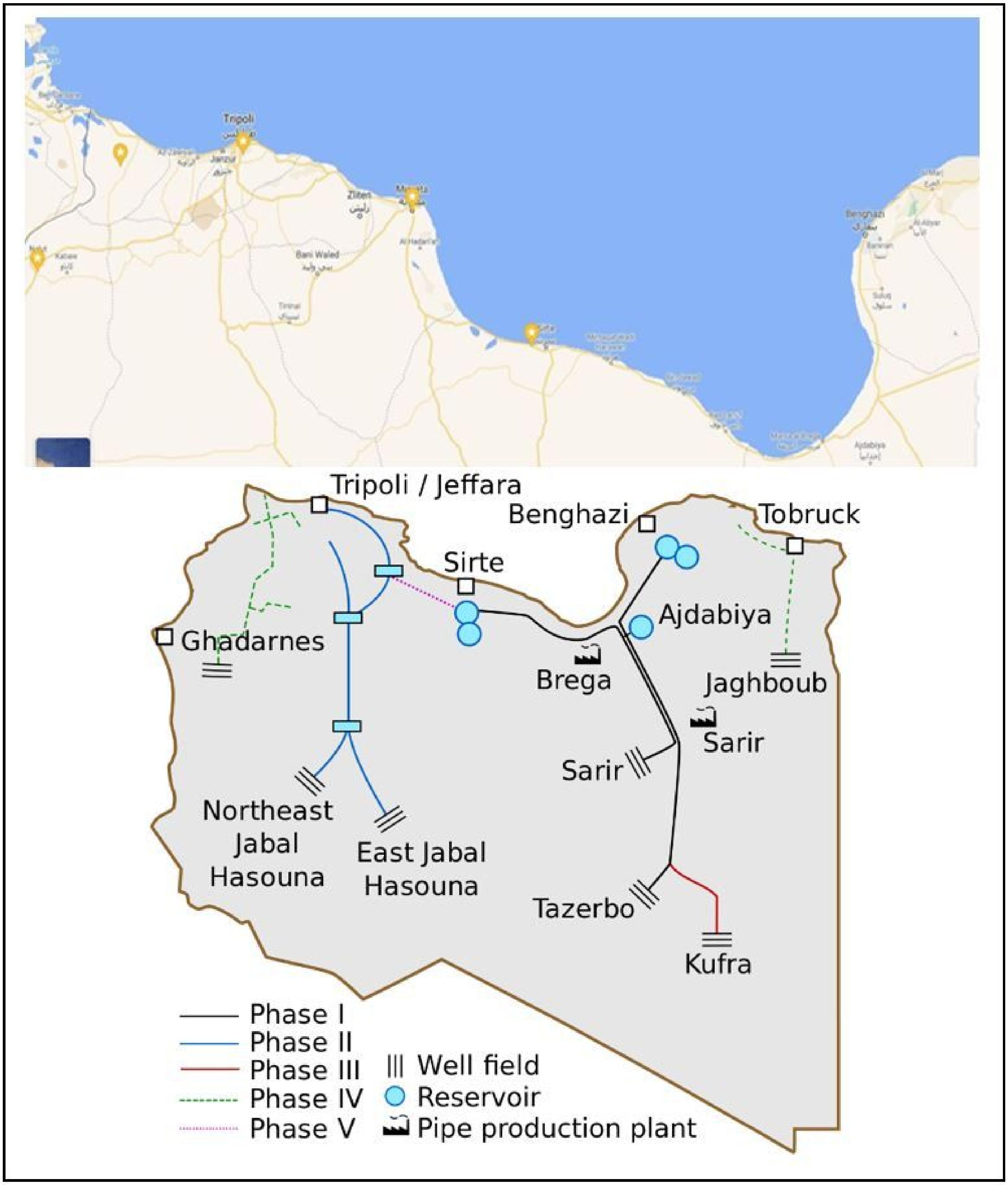
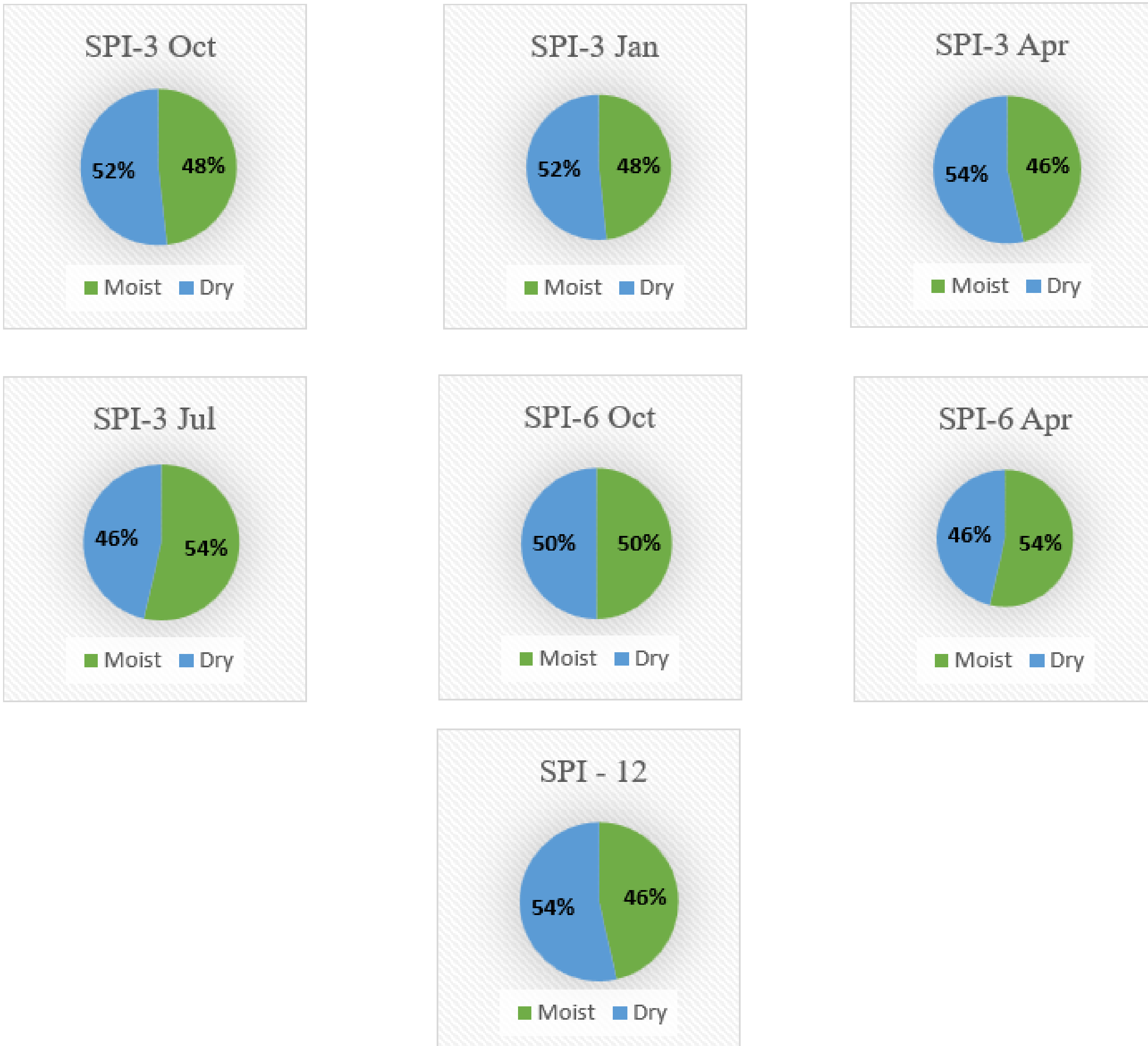
# Figures



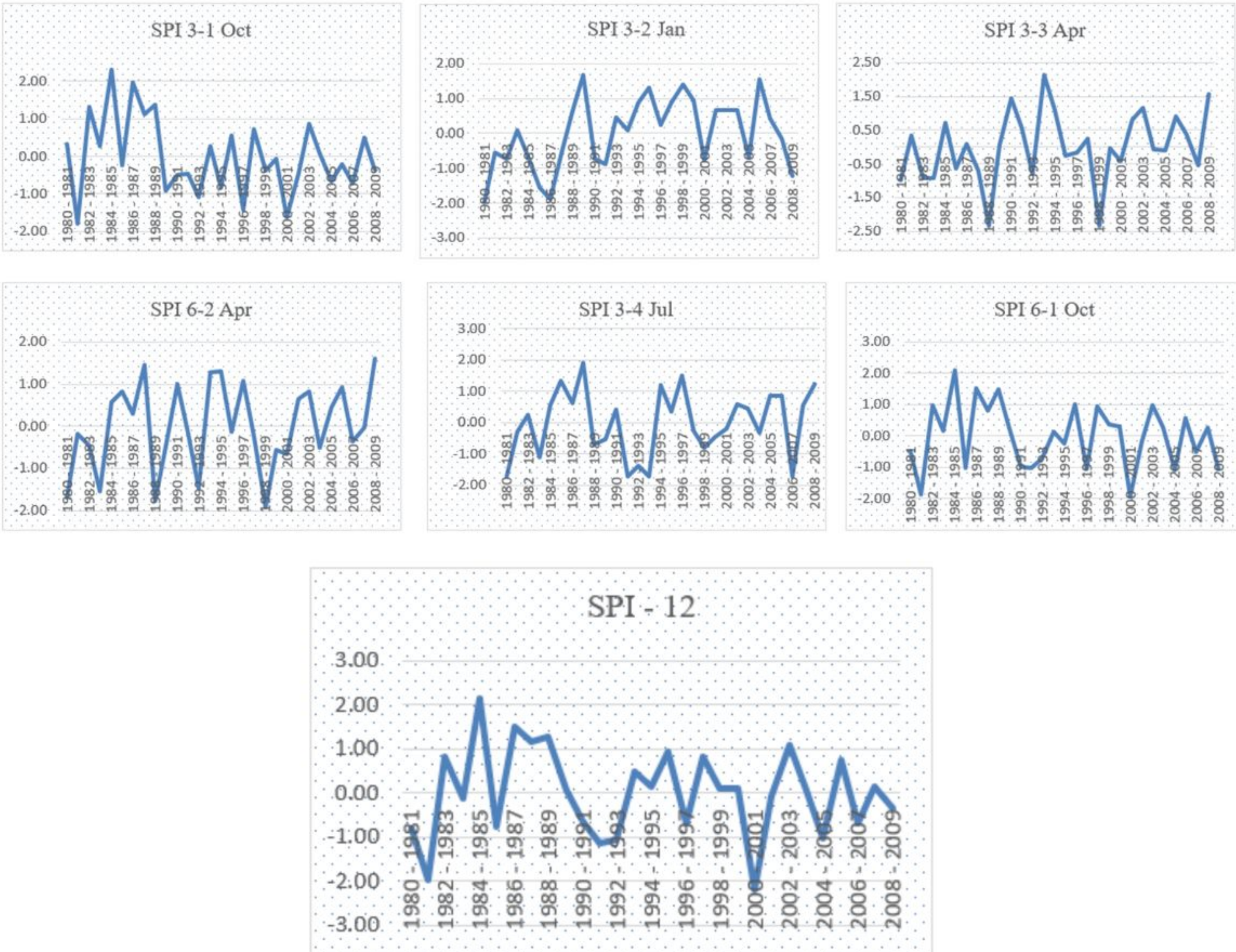

## Figure 1

Northern Libya and locations of rainfall monitoring stations by Google Maps and (Paek et al., 2021)




## Figure 2

Dry/moist period distributions according to the 3-,6-,12- month SPI values in the Zuara Station.




## Figure 3

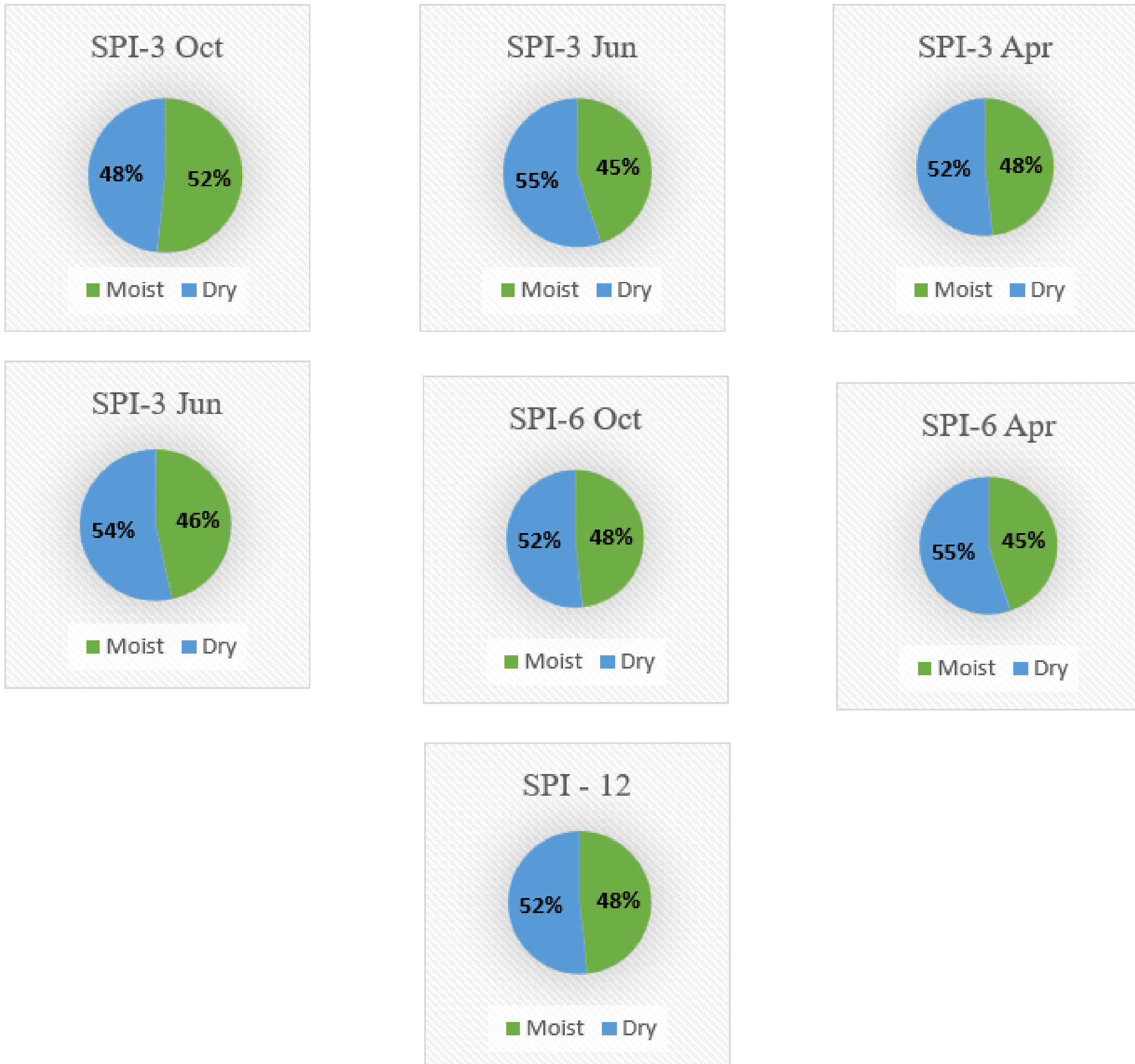
Temporal distribution of 3-, 6-, and 12-month SPI values of the Zuara Station.


## Figure 4

Dry/moist period distributions according to the 3-,6-,12-month SPI values in the Tripoli station.

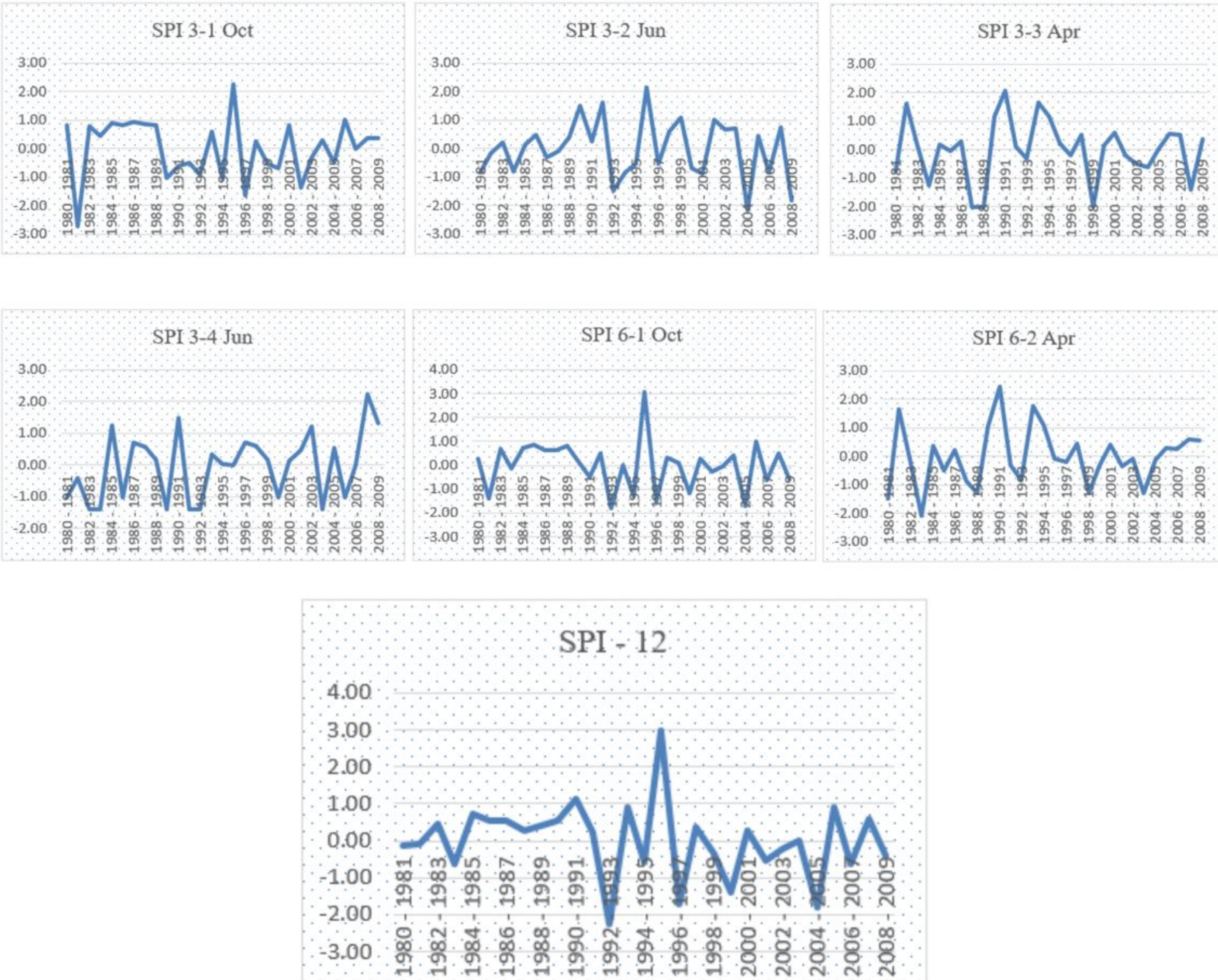
## Figure 5

Temporal distribution of 3-,6-,12 month SPI values of the Tripoli station.




## Figure 6

Dry/moist period distributions according to the 3-,6-,12- month SPI values in the Nalut station.




## Figure 7

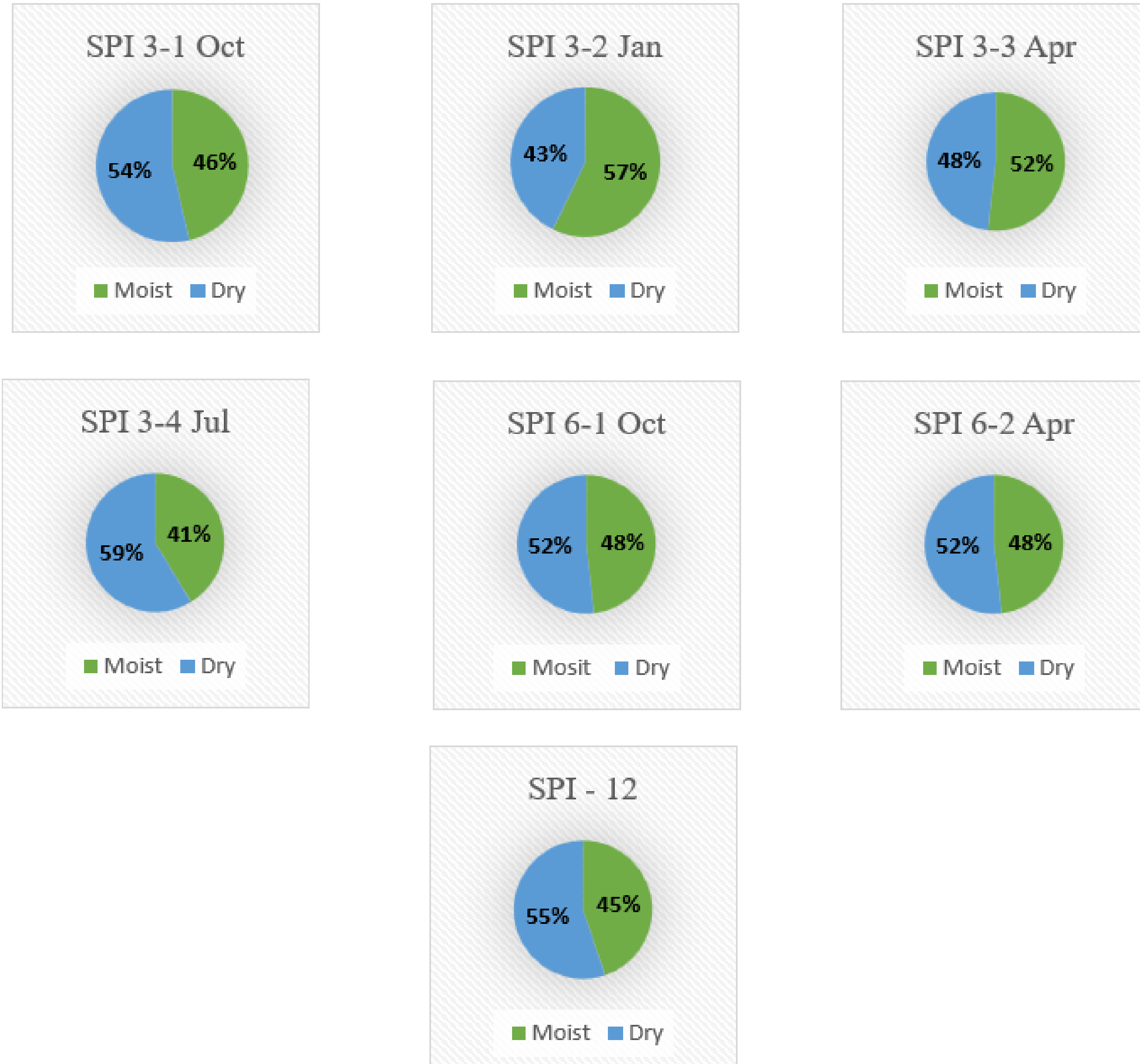
Temporal distribution of 3-, 6-, and 12-month SPI values of the Nalut station.

## Figure 8

Dry/moist period distributions according to the 3-,6-,12- month SPI values in the Misurata station.

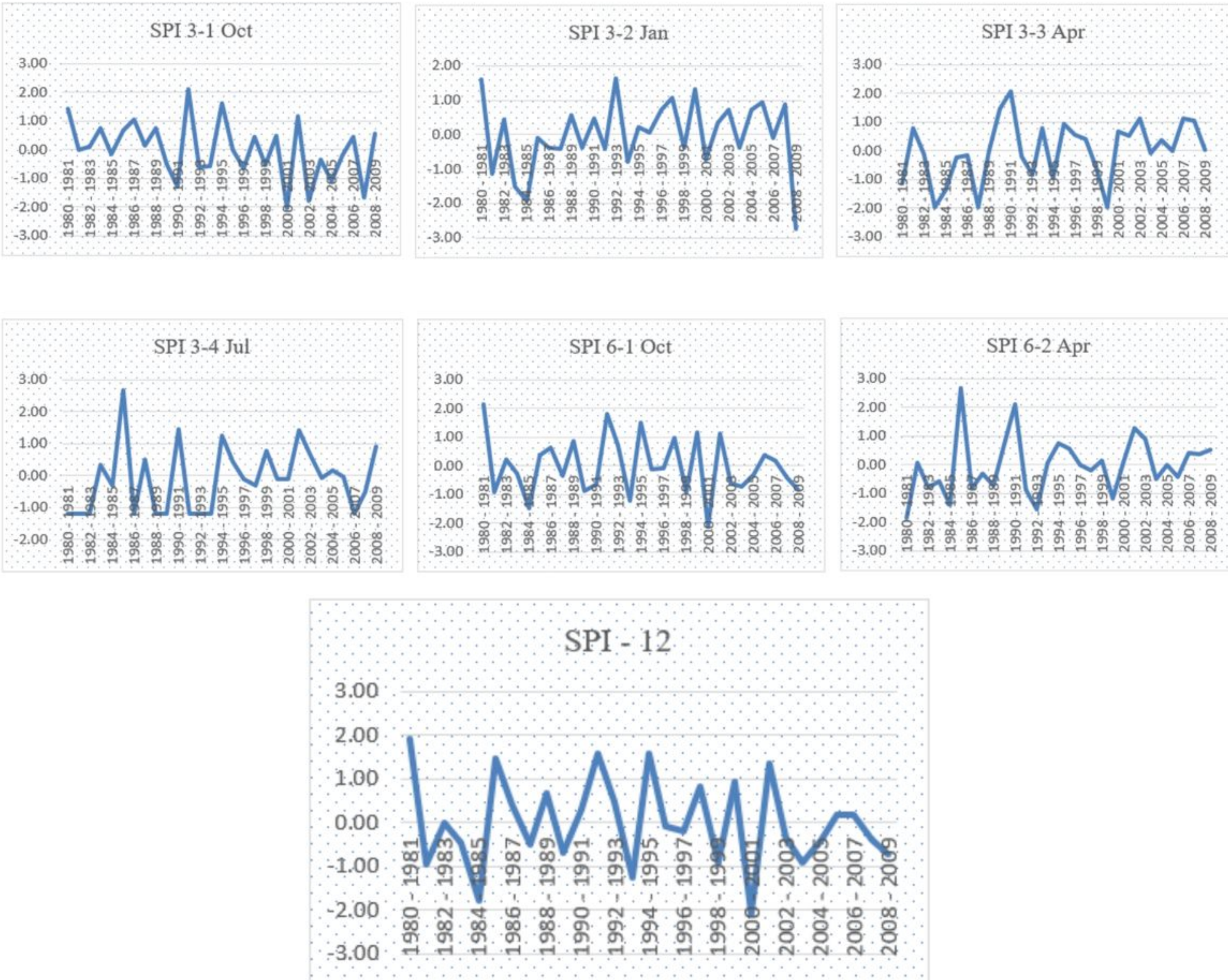
## Figure 9

Temporal distribution of 3-, 6- and 12-month SPI values of the Misurata station




## Figure 10

Dry - moist period distributions according to the 3,6,12month SPI values in the Sirt station.




## Figure 11

Temporal distribution of 3-, 6- and 12-month SPI values of the Sirt station.